Flood Risk Management Agent Based Modeling

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[1]*Introduction & Methodology*
[2]*Results & Discussion*
[3]*Abstract & Conclusion*
[†]*The group members contributed as mentioned part of report respectively.*

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Abstract

This paper examines the application of an Agent-Based Model (ABM) for flood risk management, focusing on the varying impact and response required at different flood risk levels. The model's simulations across low, moderate, and high flood risk levels provide critical insights into flood spread, water levels, human evacuation, and property damage. At low risk levels, the flood impact is minimal and manageable, with limited property damage and minimal disruption to daily life. Moderate risk scenarios entail substantial property damage and more complex evacuations, while high-risk scenarios reveal severe flooding, extensive property damage, and prolonged evacuation times. The study emphasizes the necessity of ongoing monitoring, environmental considerations, comprehensive evacuation plans, and robust flood defenses to mitigate damage and loss of life in high-risk flood areas.

1. Introduction

Agent-based modelling and simulation (ABMS) is a new approach to modeling complex systems composed of interacting, autonomous agents. Agents have behaviors described by simple rules and interactions with other agents, which influence their behaviours. By modeling agents individually, the full effects of diversity among agents in their attributes and behaviors can be observed, giving rise to the behavior of the system as a whole. Self-organization can often be observed in such models, as patterns, structures, and behaviors emerge through agent interactions.[5]

ABMS emphasizes modeling the heterogeneity of agents across apopulation and the emergence of self-organization. It offers a way to model social systems that are composed of agents who interact with and influence each other, learn from their experiences, and adapt their behaviours so they are better suited to their environment[5]. Applications of ABMS span a broad range of areas and disciplines, including flood risk management, stock market, supply chains, predicting epidemic spread, adaptive immunesystem, consumer purchasing behavior, ancient civilizations, battlefield engagement, and more[5].

Advancements in specialized agent-based modelling software, new approaches to model development, data availability at increasing levels of granularity, and computer performance have made these applications possible. The growing interest in ABMS is evident in the number of conferences and workshops dedicated to or having tracks on agent-based modelling, peer-reviewed publications in discipline-specific academic journals, openings for people specializing in agent-based modelling, and funding agencies supporting programs that require agent-based models[5].

Flooding is among the most frequent and destructive natural disasters worldwide, driven by various factors such as climate change, urbanization, and inadequate planning. Sri Lanka's 2024 flood disaster in the southwestern regions exemplifies the devastating impacts of extreme weather events. Torrential rains led to widespread flooding, displacing thousands, damaging infrastructure, and inflicting severe economic losses. This disaster highlighted the pressing need for resilient flood risk management strategies to mitigate future impacts[6].

This report introduces a model designed to simulate flood events, assess their impacts on communities, and evaluate the effectiveness of different flood risk management strategies. By replicating real-world flood scenarios, such as the 2024 disaster in Sri Lanka, the model aims to provide insights into how management strategies—like early warning systems, evacuation plans, and structural defenses—can mitigate damage and improve community resilience.

Torrential rains led to widespread flooding, displacing thousands of residents, damaging infrastructure, and causing significant economic losses. By simulating such events, the model can provide insights into how different management strategies, such as early warning systems, evacuation plans, and structural defenses, can mitigate the damage and improve community resilience. The model will help identify the most effective measures to protect vulnerable populations, optimize resource allocation during emergencies, and guide long-term planning to reduce future flood risks[8].

In this model answers the following key points :

1. It examines what are the main factors trigger flood disasters and at what levels they occurs (give a brief idea for each factor condition's Impacts).
2. Estimate the past & future losses if the flood disaster occurred in a location.
3. Helps to analyze flood disaster forecasts and precautions

The model focuses on three key objectives. First, it examines the main factors that trigger flood disasters and identifies the threshold levels at which they occur. Factors such as rainfall intensity, river overflow, and urbanization are analyzed to understand their contributions to flood risks and their impacts. Second, the model estimates both past and future losses that could result from flood events in specific locations, providing valuable information for resource allocation and disaster preparedness. Third, it aids in the analysis of flood disaster forecasts and precautionary measures, helping authorities and communities implement effective strategies for risk reduction.

To achieve these objectives, the model leverages Agent-Based Modeling (ABM) alongside advanced tools such as NetLogo, AnyLogic, and the ODD (Overview, Design concepts, and Details) protocol. ABM is particularly useful for simulating complex interactions within human and natural systems, enabling the analysis of how individual and collective behaviors influence flood outcomes. In this context, agents represent key stakeholders, including residents, local authorities, and emergency responders, each making decisions based on predefined rules and responding dynamically to changing conditions.

NetLogo and AnyLogic are integrated as the primary platforms for developing the model. NetLogo's user-friendly interface and extensive libraries make it suitable for simulating large-scale scenarios with multiple interacting agents, while AnyLogic's versatility allows for incorporating both discrete event and system dynamics models, enhancing the robustness of the simulation.

The ODD protocol is used to structure the model, ensuring clarity and reproducibility. This methodology guides the detailed documentation of the model's objectives, design concepts, and implementation details, allowing other researchers and practitioners to replicate or adapt the model for different contexts[1].

By applying these methods and tools, the model offers a comprehensive approach to flood risk management. The results can inform decision-making by identifying the most effective measures for protecting vulnerable populations, optimizing emergency response plans, and guiding long-term development strategies aimed at reducing future flood risks. Ultimately, this work contributes to building resilient communities capable of withstanding and adapting to increasingly frequent and severe flood events in a changing climate.

2. Methodology

2.1. Assessment of the studies using the overview, design, detail protocol

2.1.1. Background on ODD protocol

The ODD protocol is a structured method for describing individual agent-based simulations (ABM), which can be confusing due to the numerous elements in ABM. The protocol aims to provide a more standardized structure for documenting model processes, enabling reproducibility and increasing methodological rigor. Initially written from an ecology perspective, the ODD has evolved over time, with some researchers removing certain components due to repetition and others addressing clarity issues. An update in the protocol has provided more clarity and expanded its applicability to all disciplines, not just ecology. The protocol has been adapted by researchers for human decision-making, provenance, and empirical data. It is a valuable tool for practitioners in the socio-hydrology domain to familiarize themselves with model structure and identify crucial information for model constituents[4].

2.1.2. Components of the ODD

The ODD protocol, with an inverted pyramid structure, describes the simulation's goal and progresses into finer details. It has three categories (Overview, Design, and Details) and several sub-components. Table 1 presents the ODD protocol's structure, highlighting categories used in this review. The selection was based on research questions and the protocol's inclusivity, ensuring not all aspects may be necessary for flood-ABM descriptions.

2.1.2.1 Overview

2.1.2.1.1 Purpose

The model aims to simulate flood events, assess their impacts on a community, and evaluate the effectiveness of various flood risk management strategies. We know about Sri Lanka's 2024 flood disaster[3], which severely affected the southwestern regions of the country. Torrential rains led to widespread flooding, displacing thousands of residents, damaging infrastructure, and causing significant economic losses. By simulating such events, the model can provide insights into how different management strategies, such as early warning systems, evacuation plans, and structural defenses, can mitigate the damage and improve community resilience. The model will help identify the most effective measures to protect vulnerable populations, optimize resource allocation during emergencies, and guide long-term planning to reduce future flood risks[8].

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2.1.2.1.2 **Entities, State Variables, and Scales**

In this model has 4 type of entities, those are residents- this is maintains randomly allocate as percentage of residents but we can implement a specific number or percentage. Second and third are infrastructure elements (e.g., buildings, roads) and natural elements (e.g., lakes, rivers, vegetation) these also set in percentage and this is help for our losses predictions impact of flood disasters. last one is emergency responders(Emergency responders, crucial in flood risk management, are modeled to simulate realistic responses, assess strategy effectiveness, and understand preparedness in mitigating flood impacts, ensuring safety, and saving lives. so they are help to minimize the losses and ext..) this is set as number of stations has that location. And Water level of rivers and lakes, Amount of precipitation, Near the ocean, Area with drainage system these are other state variables and we are take a location and set all impact factors levels and all things to observe in each conditions and study what happens in each situations.

Process Overview and Scheduling Key processes in this study include creating the environment and adding agents, fix any type of locations with any entities, state variables and scaling with a time steps to observe how to spread flood and losses at the same time how to changing water levels in lakes and rivers and how to changing other factors and predict the losses, explain a flood any situation with our assumptions. and to state different type of conditions to create a location and observe all factors to state the forecasting flood disasters.

- **Time Steps**: Model runs in discrete time steps (e.g., short-run as hourly or days and long-run as months, years).
- **Processes**: Flood onset, agent responses, movement, interaction, and flood recession.

2.1.2.2 **Design Concepts**

2.1.2.2.1 Basic Principle, Emergence and Adaptive behavior

The basic principle of this study is to use an agent-based model to simulate flood risk management in river basins, exploring how flood risk emerges from interactions between agent-agent, agent-environment and also agent decision making(Figure 1).

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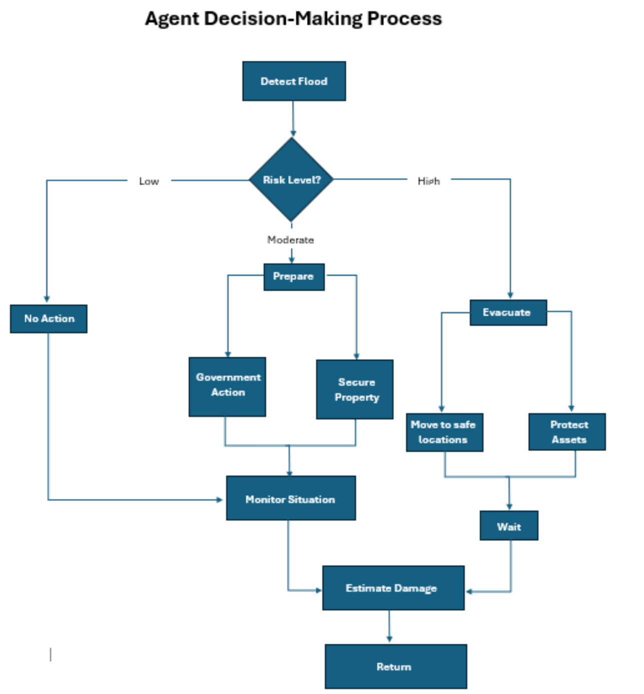


Figure 1. Decision-Making Process of residents and emergency responders during a flood event. This chart outline steps from detecting flood, assessing flood risk, actions of agents, and monitoring the situation until the flood reduces.

Figure 1 explain the decision making process of residents and emergency responders. This figure shows how agent make decision after detecting flood up until they return to their normal day. After detecting a flood, agents make different decisions based on the flood risk level which are low, moderate and high. If the flood risk is at a low level, agents tend to do nothing and instead they monitor the situation until the flood reduces while continuing their normal lives. If the flood level is moderate, agents prepare for different actions which are property securing and government action to reduce flood such as implementing flood control gates, drainage systems and barriers or floodgates will be opening/closing, if there are any floodgates. Then they will continue to monitor the situation until they can return to their normal life. If the flood level is high, then their decision becomes more critical. Evacuation process happens in this risk level. Residents will be evacuated to safe locations while protecting their valuable assets. Then they will wait in their current safe places until the water level decreases enough for them to return to their daily life. That explains the basic idea of how the agents make decisions depending on the flooding situation.

Human complex behavioral arise from the interactions of individual agents to flood risk such as people choosing same road for evacuation can lead to unexpected patterns of movements like heavy congestion on that road, due to the collective behaviors of each agent. Moreover, some areas might receive more assistance based on real time unexpected information resulting in unexpected patterns in how emergency services respond to a flood event. Not only the human agents, but environmental factors and infrastructure element together create unpredictable patterns, changing how water moves and sometimes making flooding worse in unexpected places. Therefore, understanding how these interactions create emergent patterns is more important in flooding situations. These kinds of emergence provide valuable insight to develop more effective and adaptive models to simulate flood risk and management[8].

Residents keep adapting their behaviors based on real time information that can be received from informal communication networks faster than the official channel, and real time flood conditions which might occur due to various emergent situations. For example, residents might decide to evacuate earlier or differently after receiving a flood warning based on their past experiences with floods. And also, emergency services might create new plans based on live information. So, exploring these adaptive behaviors helps to develop a more flexible and responsive flood risk management system[3].

2.1.2.2.2 Objectives, Prediction and learning

The main objective of this study is to understand and improve flood risk management in river basins by using an agent-based model. To understand and improve flood risk management, this study aims to develop a flexible and effective Agent Based model including user friendly graphical user interface by observing and analyzing interaction between individual agents that influence flood risk including emergence and adaptive behaviors. Furthermore, the model will help to identify the most effective ways to protect communities and will provide long term planning to reduce future flood risk.

Finally, this study aims to provide valuable insights into difference management strategies such as early warning systems, structural defenses, policy making and resource allocation by testing under various scenarios. And also, these insights will provide valuable information for different fields like urban planning etc.

This model can predict how various factors that influence flood risk affect risk management under different scenarios. Therefore, one of the predictions will be identifying the most congested evacuation routes during evacuation process using agent interactions, including emergence and real time information. Furthermore, the model will be able to estimate evacuation time and response time of emergency services under different situations, providing crucial information for risk time management and for better resource allocation and response planning[8]. Additionally, this model will be able to adapt and improve its predictions based on new data such as adaptive behaviors of residence based on past experience and learning of residence and emergence as explained in section 2.1.2.2.1[8].

2.1.2.2.3 Sensing

To improve accuracy of the model, data from various formal and informal sources will be used and adapted into this model. Mainly the model will gather data such as whether conditions, river flow rates and flood level etc. in a formal way. Furthermore, this model incorporates informal data like the past experience of resident into the model, which helps to define effective rules on agent behaviors and improve its predictions.[8].

2.1.2.2.4 Interaction

In the flood risk management agent-based model, much of the understanding and mitigation of flood impacts lie in how well such diverse entities can interface with each other. Residents interact with their physical space as they respond to warnings issued for a flood event by making decisions about whether to evacuate and by what routes. Such decisions may then bring about emergent behaviors that complicate issues at hand, such as timely evacuation and great risks, due to traffic congestion on major evacuation routes. Emergency responders interact with the resident population on matters of assistance, and advice regarding evacuation, and rescue operations. Their effectiveness depends on real-time communication and coordination between them and the residents they are assisting.

This also includes the interaction of the floodwaters with infrastructure elements such as buildings and roads, relating to the extent of physical damage and economic losses. Other natural factors are the rivers and vegetation, which normally interact with the floodwaters to affect the spread and intensity of the floods. In this way, the model picks up these complex interactions to simulate how strategies for improved communication systems, better infrastructure planning, and efficient infrastructure in terms of emergency response protocols can be tuned for enhanced community resilience and reduced adverse effects of floods. Figure 2

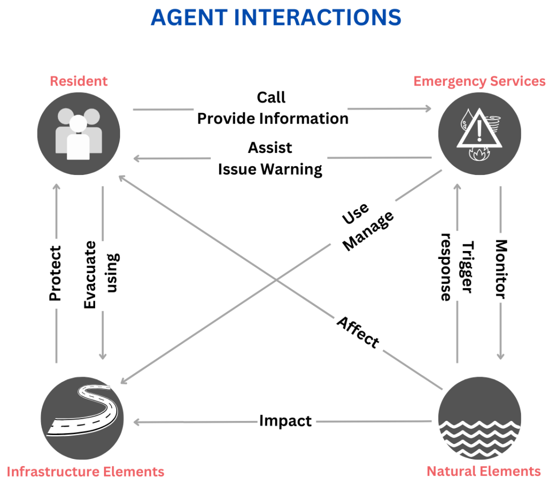


Figure 2. Agent Interactions: Basic interactions among residents, emergency services, infrastructure elements and natural elements

Above Figure 2 shows basic interaction between each agents which considered in this model Emergency services issue warning about floods which triggers response by natural elements like river to residents and assist them during the flood by securing properties and rescuing by using infrastructure element lie road and buildings while managing them. And residents call emergency services requesting help, assist or to give current information about flood. Then residents evacuate using infrastructure elements such as roads, buildings, etc. On the other hand, infrastructure elements protects residents. And also, natural elements like rivers and lakes affect residents and impact infrastructure elements.

2.1.2.2.5 Stochasticity

Randomness and variability, or stochasticity, constitute a very important component of this flood risk management agent-based model. One of these aspects concerns modelling real-world uncertainties. For example, we randomize the initial distribution of residents in the modelled area to understand the variability in population density and settlement patterns. We further stochastically generate the extent and intensity of flood events based on historical data and weather pattern trends, making a model setup that simulates a large space of probable flood scenarios. In resident evacuation behaviour, stochasticity infiltrates into their decision-making and movement patterns to capture individual differences and unpredictability of human actions.

Moreover, it is also possible to randomize the deployment and efficiency of emergency responders to simulate potential logistical challenges or actual decisions taken in real-time situations. In this way, this stochasticity will enable the model to run through several scenarios to give a solid analysis of the flood risk management strategies under varying conditions, thereby offering an understanding of possible impacts and mitigation measures in their entirety.

2.1.2.2.6 Collectives and observation

In the flood risk management agent-based model, collectives are representations of groupings of agents that act together or exhibit some other kind of collective behaviour in the case of flood events. For example, evacuation of residents often takes place in groups—families or community clusters—that engender collective movement patterns and hence cause road congestion or bear on the success of evacuation plans. Emergency responders will also operate in teams, coordinating their efforts to rescue people, provide medical aid, and manage shelters. Such collective actions are important in ensuring efficient and effective response to flood events. Furthermore, community organizations and local governments also act as collectives in carrying out flood preparedness measures, disseminating information, and facilitating recovery efforts. Simulation is capable of modelling such collective behaviours to evaluate the benefits and challenges of coordinated actions, pinpointing possible bottlenecks and proposing improvements in strategies for collective response to improve overall flood resilience.

For any flood risk management agent-based model, observation is also a very important component, where by variables and results of the simulation can be monitored and analyzed. Observed key variables include, among others, the number of residents evacuated to safety, the extent of infrastructure damage and intensity of the damage, the efficiency and effectiveness of emergency measures taken, and the economic impact of the flood event. The changing water level, precipitation rate, and floodwater movement over the landscape are recorded by the model. The activities of residents and responders map not only the behaviours and interactions but also understand the patterns and emergent phenomena. From this type of observation, very useful data relating to the testing of the different flood management strategies, known weaknesses of plans, and proposing improvements can be gathered. The model, through the observation and analysis of such variables in a systematic way, can shed light on the dynamics of flood events and different mitigation measures that may have an impact on response measures, hence leading to effective decision-making in flood risk management.

***2.1.2.3* Details**

The Details component of the model development process consists of three sub-components: initialization, sub-models, and model analysis and accessibility. Initialization involves setting variables for agents and the environment before the main simulation starts, and can be based on existing data, probabilistic determination, or a combination of both. Sub-models form the ABM and are often run independently and programmatically interrelated due to different parameters. Model analysis is often suggested as a mandatory step to calibrate, verify, validate, and analyze model results. Validation occurs in the post-simulation phase, and two approaches are comparing model outputs to observed data and through sensitivity analysis.

2.1.2.3.1 Initialization

This model starts off with a location that is specified for its entities, state variables, and scales. This can be implemented as a roughly $5 \times 5\ \mathrm{km}^2$ area, and a baseline flood scenario (this is other rain falling, water levels of lakes and rivers, near the ocean or not, and area with drainage system or not). For example, set residents as a percentage of residents, infrastructure elements (e.g., buildings, roads), and natural elements (e.g., lakes, rivers, vegetation). Some entities are set as percentage and others as number of lakes likewise and emergency responders also set number of stations to get the model going.

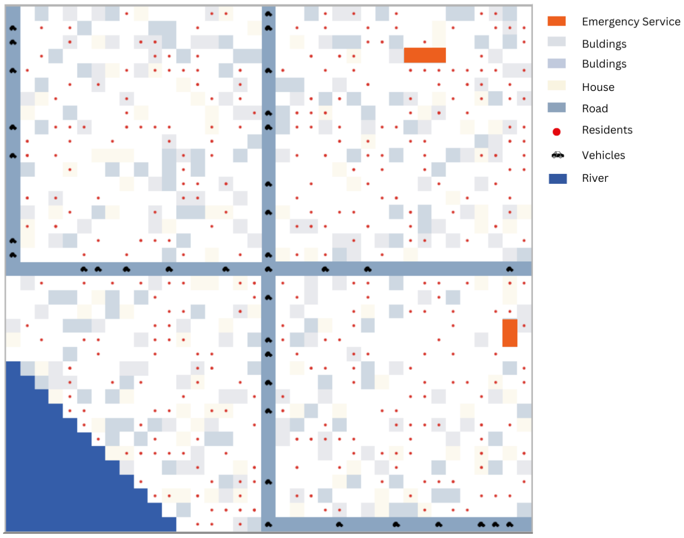


Figure 3. Virtual City in our model, including river as natural element, roads and building (blue blocks) as infrastructure elements, residents (red dot) and emergency services (red blocks)

2.1.3. Input Data

If we first implement the $5 \times 5\,\mathrm{km}^2$ area using historical flood data, topographic maps, and demographic data then that area fixed and no other input data.

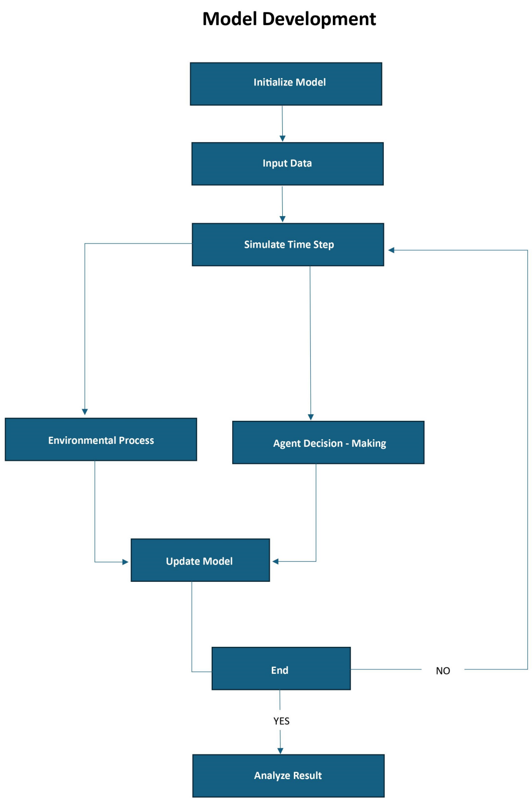


Figure 4. High-Level view of the model

The above Figure 4 shows high level view of the main components and process of the model development. Model starts by setting up its initial state. It involves creating the environment. initializing agents (river, buildings, residents, agents, emergency services) and setting parameter values. Then by inputting data such as external data (historical rainfall data, topographical information), the model is being developed. Next step is simulating time step(days). This represents a unit time in the simulations. It is the beginning of the loop and runs several times according to initialized simulations run time. This loop includes environmental processes such as simulating rainfall and water flow in the river system, etc. and agents' decision-making process such as resident decisions and government decisions. Then after based on above two processes the current state of the model will be updated including agents' statuses, environmental changes. Then the model checks whether the simulation will end or not. If the model ends, then it will analyze the results and display the results. If not, the model will continue to the next day.

2.1.4. Submodels

Here, we define the following three sub-models:

1. Forecasting the flood disaster model
   Initially, we establish the ideal flood disaster conditions and forecast when those criteria would be met to provide information to emergency responders and entities (residents).
2. Determine the flood losses model
   We will calculate the extent of the damages to those entities by starting the model, first we determine roughly $5 \times 5\,\mathrm{km}^2$ area and divide $100 \times 100\,\mathrm{m}^2$ sub-areas and observing the flood distributions, seeing the flood spreading, and observing the water levels to display a plot what is the water level of each sub-areas. And we are develop a model from the **secondarticle** article methodology. below the image show that image show sample methodology.

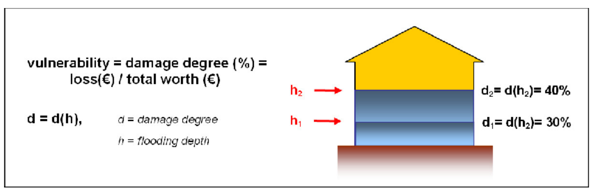
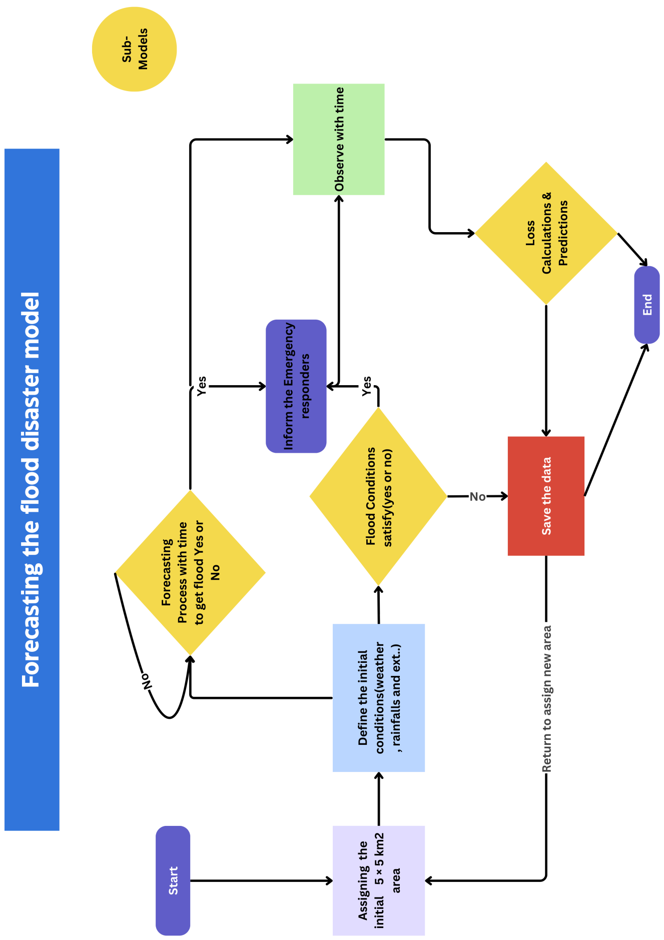


Figure 5. damage analysis of our sub-models - get in article(**secondarticle**)

3. Setup the emergency responder
   Establish first the parameters that will allow emergency responders to react, save lives, and reduce damage to local entities. And below the flow chart show how to works this sub-model and relationship of other sub-models.

Figure 6. Flow chart of our sub-models: I this flow chart represents what are the sub-models in this model, our model what can do and how to works and overview of our flood model.



2.2. Implementation of NetLogo and AnyLogic software

2.2.1. NetLogo

The flood risk simulation is designed using the NetLogo platform to model and analyze the impact of flooding on a community. The simulation assesses the effect of various factors such as water sources (lake, river, rainfall), resident vulnerability, and mitigation strategies (beach barriers, responders). This methodology describes how the model was developed and implemented, along with its core components and functions.

The simulation environment is initialized with global variables representing time, water level, and overall damage. Residents, represented as turtles, are divided into three groups: individuals, trees, and houses, each with unique thresholds for flood damage.

1. Resident Groups Residents are categorized by height into three groups as **Group 1 (Blue)**,**Group 2 (Green)** and **Group 3 (Red)**. Each group has a predefined height limit, above which they begin taking damage as water levels rise.
2. Water Sources The model includes adjustable water sources:
   - **Lake and River:** Represented by turtles with size and position determined during setup. Their contribution to the water level is based on user-defined slider values.
   - **Rainfall:** Affects water levels incrementally and is controlled by a slider.
3. Infrastructure Roads are divided into main roads (one vertical and one horizontal) and sub-roads. The user defines the number of roads, which are represented as black lines. This infrastructure helps simulate real-world conditions by introducing obstacles and pathways for flood movement.
4. Mitigation Strategies Beach Barriers are Reduce overall damage when enabled by providing coastal protection. Responders are Represent emergency services that mitigate damage by reducing the flood's impact on the community.

- **Global Variables:** These track essential metrics like evacuated-humans, total-water-level, buildings-covered-in-water, and more.
- **Agent Breeds**: You've defined humans, cars, and boats as separate breeds, each with its own properties like speed, evacuation status, and target.
- **Patch Properties**: Patches track their status as roads, buildings, water depth, and other key details.
- **Building Types**: Buildings are categorized into residential, commercial, landmark, and special.
- **Water Spread**: Water is spreading based on slope depth and gradually filling the environment.
- **Evacuation Logic**: The model tracks evacuation efforts by cars and boats, with some agents potentially getting trapped or dying due to water levels.

The simulation runs iteratively, incrementing the time variable at each tick. The water level increases based on the lake, river, and rainfall inputs. The monitor-damage procedure assesses damage to each resident group based on the water level and their respective height thresholds. If the water level exceeds the threshold for a group, the model calculates damage and removes the affected turtles (residents). Damage is further adjusted based on the presence of beach barriers and responders.

The model plots water level changes over time to provide a visual representation of flood progression and its impact. Given the complexity, ensuring the model runs smoothly as the simulation progresses is critical. You may want to consider performance optimizations, especially when spreading water, counting buildings, or updating patch properties. Consider breaking up complex procedures into smaller functions. For example, water spread and evacuation checks can be modularized further for clarity. The evacuation logic could be enhanced by introducing smarter decision-making for humans, like prioritizing routes with lower water levels or closer buildings. You can add more detailed plotting to track important statistics like damage, evacuated-humans, and water spread over time. Implement more nuanced behaviors, like adaptive response when water levels exceed thresholds or when certain buildings are submerged.

Damage Calculation

Vulnerability refers to the extent of damage to vulnerable elements resulting from a natural event. Factors such as water level, flow speed, suspended and floating load, contaminants, and flood duration determine flood-induced damage on structures. The depth of flooding is often considered as the only indicator for flood event magnitude. Stage-damage curves, also known as loss functions or vulnerability functions, describe the direct effect of floodwater on different types of exposed elements. These curves estimate the damage level as a value between 0 (no damage) and 1 (total destruction). These curves should be studied to describe the effect of floodwaters on specific types of exposed elements and can be used to simulate damage for future inundations. Different curves should be created for different geographical areas and applied to limited homogeneous territories. The May 2002 flood in the Boesio Basin used data to develop stage-damage curves for residential buildings with basements[2].

Damage calculation formula is : [2]

$$\text{Damage Degree (\%)} = \frac{\text{Loss (€)}}{\text{Ground Floor Value (€)} + \text{Basement Value (€)}} \times 100$$

we just implemented as,

$$\text{Damage} = (\text{Water Level} - \text{Height Threshold}) \times 0.05 \times 15000$$

This calculation is applied for each affected group. The model accounts for additional mitigation by reducing the damage proportionally if beach or responder options are enabled. and these values are just take in as modified to take some aproximated values to we modeled in NetLogo model.

2.2.2. AnyLogic

This research aims to understand the complex behavior of people during an evacuation in the City of Gold Coast, capturing the dynamics of evacuees in the case of a flash flood and measuring evacuation times under stochastic assumptions. The architecture integrates an agent-based simulation model and a geographical information system (GIS) data bases. AnyLogic® is the selected software for the model implementation, which supports all three well-known modeling approaches: system dynamics, discrete event simulation, and agent-based modeling [7].

AnyLogic includes a graphical modeling language and allows users to extend simulation models with Java code. The Java nature of AnyLogic allows for custom model extensions and the creation of Java applets, making it easy to share or place on websites. The Professional version allows for the creation of Java runtime applications, which can be used as a base for decision support tools.

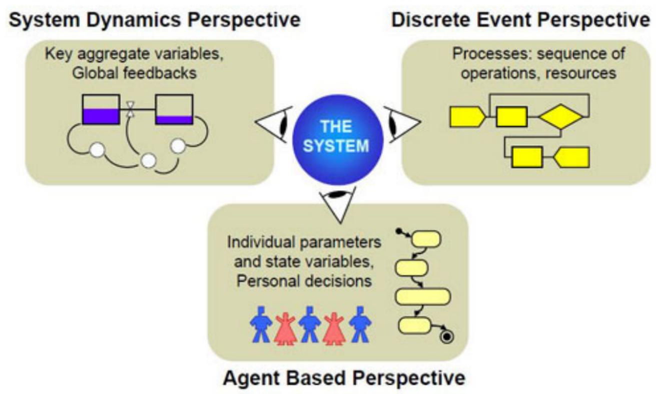


Figure 7. Three simulation approaches [7]

Agent-based modeling (ABM) has evolved over the last decade, allowing for more applied and policy-oriented topics due to better development environments and faster computers. This advancement has led to a deeper understanding of complex interdependent processes and improved decision support tools[7].

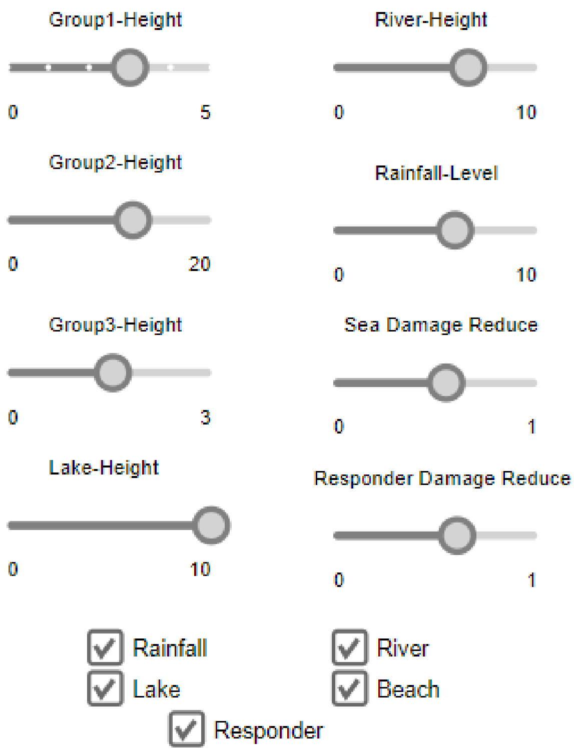


Figure 8. Parameters defined in AnyLogic Model and these are adjustable and analysis

The model interface includes sliders for setting different variables and checkboxes for toggling specific flood-related factors. Key elements include:

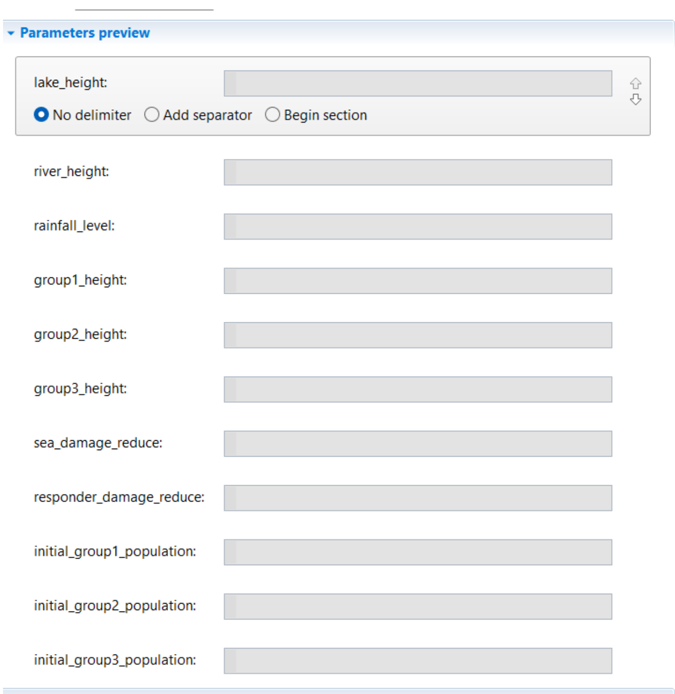


Figure 9. Parameters defined in AnyLogic Model and these are adjustable and analysis

- **Group Heights (Group1, Group2, Group3):** These sliders control the flood resistance threshold for different resident groups, likely representing various types of buildings or vegetation with varying flood tolerance.

- **River-Height, Lake-Height, Rainfall-Level:** Sliders that allow users to simulate different water inflow scenarios, influencing the overall flood risk.
- **Sea Damage Reduce, Responder Damage Reduce:** These sliders likely simulate damage mitigation measures, such as flood defenses or emergency response capabilities.
- **Checkboxes (Rainfall, River, Lake, Beach, Responder):** These options enable or disable specific environmental factors or management strategies to observe their impact on the flood scenario.

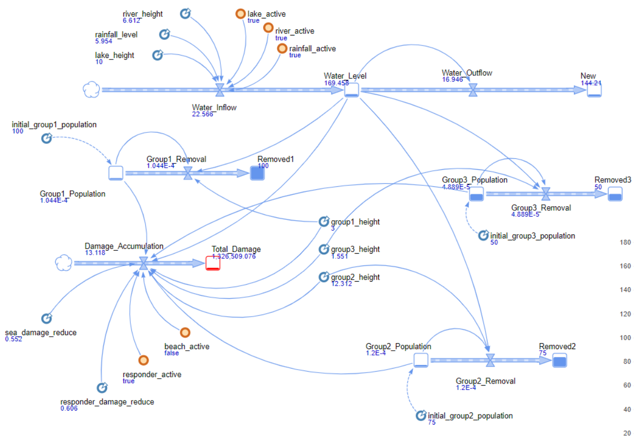


Figure 10. parameter Addin

This model simulates flood scenarios with customizable inputs, offering a platform to analyze flood risks and evaluate the effectiveness of different mitigation measures. The adjustable sliders and checkboxes allow for a range of scenarios, from varying water levels to the impact of emergency responses and environmental features. The real-time plotting feature provides visual feedback on water levels over time, aiding in understanding how different strategies can influence the outcome of a flood event.

3. Results & Discussion

This section presents a comprehensive analysis of the Agent based model designed for Flood Risk Management. The model simulates the various flood scenarios across three risk levels such as low, moderate and high. Flood spread areas, water level, human evacuation and time, and property damage will be especially examined under this section showing how these outputs respond to changes in environment and population parameters for each risk level and will be provide valuable insight for flood management strategies. So, each risk level monitor,

- Flood spread areas over time
- No. of waters spread areas
- No. of initial low risk areas (where the flood begins)
- No. of humans evacuated to nearest buildings
- No. of humans leave the area (self-evacuations)
- No. of humans' dead
- Time for human evacuation
- Property damage estimate
- Water level spread over time

In this model, flood levels are determined in advance by monitoring rainfall. And flood spread from lower ground to higher ground according to the initial slopes assigned at the beginning. Therefore, people act according to the warning of the flood risk level. At the low risk level, properties and humans are barely affected by the flood, so people continue their daily lives. At the moderate risk level, the damage level is considerably higher, and people begin to self-evacuate, with some leaving the area. At the high-risk level, the flood spreads throughout the entire area, causing significant damage to properties and humans. People in high risk areas evacuate to the nearest safe buildings, while some leave the area altogether. Responders(boats) save and evacuate people in the buildings to another safe place outside the area. The model estimates total damage based on the number of buildings affected by the flood and the reduced sea damage level. When the human population changes, all other factors change accordingly. Furthermore, the flood water level is based on river height, lake height, and rainfall level. Key factors of this model are,

- Human population (100-500)
- Rainfall level (1-10)
- River height (0-100)
- Lake heights (0-100)
- Beach (On/Off)
- Sea damage reduces (0-10)

The following sections will discuss the results for each flood risk level.

1. **Low Flood Risk Level**

   In the low-risk scenario, which was detected by rainfall level, the model was configured to simulate a situation where the flood risk is minimal and properties and humans are barely affected by the flood, so people continue their daily lives. The primary focus was on how flood spread areas, water levels change over time and property damage, with minimal impact expected on human activities and property.

   The simulation results indicated that, at the low-risk level, after (15-20) hours, the flood covers (6-8) % of the ground, and the water level reaches a maximum height of (90-100) cm within the first (2-3) hours(Figure 7) . The estimated property damage is relatively low and approximately Rs. (10,000 - 15,000), damaging 7% of the total properties.

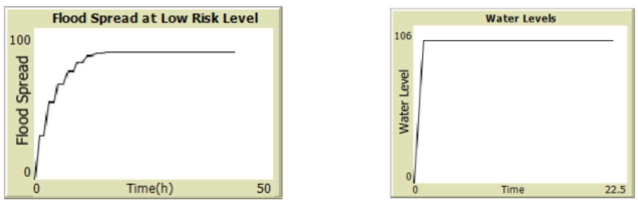


Figure 11. Flood spread and water level at low risk level over time(hours)

But as the river height, lake height, and rainfall level increase, the water level reaches a maximum of (200-210) cm in (1-2) hours(Figure 8), with estimated damage over Rs.20,000.

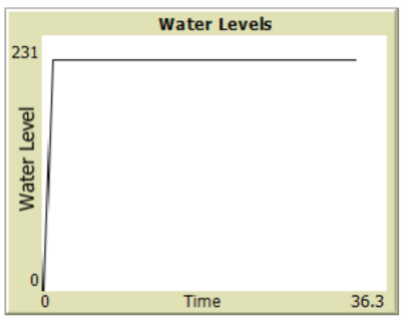


Figure 12. Flood spread and water level at low risk level over time(hours) when the river height, lake height, and rainfall level increase

As the flood impact is low at the low risk level, people continue their daily lives. Therefore, human population doesn't influence any other factors. This suggests that in low-risk scenarios, immediate evacuation might not be necessary, as the flood's progression and impact are manageable.

These findings are critical for flood risk managers, as they suggest that resources could be better allocated to monitoring and controlling the flood rather than doing unnecessary immediate evacuations. However, monitoring the level further is still essential to respond quickly if conditions worsen.

2. **Moderate Flood Risk Level**
For the moderate flood risk scenario, the model was adjusted to represent conditions where flood risk is neither minimal nor extreme. This scenario examines the flood spread, water level, the evacuation process and time, and the resulting property damage at the high-risk level.

At the moderate risk level, the flood covers (30-40) % of the ground after (40-48) hours. The water level reaches a maximum height of (105-110) cm within 2-3 hours(Figure 9). The simulation shows that property damage is significantly higher than in the low-risk scenario, with estimated damage reaching approximately Rs.150,000 damaging nearly 50% of properties. Human behavior changes notably in this scenario because they tend to evacuate by leaving the area and evacuate to safer buildings. The evacuation process takes about (30-40) hours. As the population increases, the evacuation time becomes longer than 40 hours due to the crowds, resulting in the loss of at least one person. Furthermore, the present of the sea, reduced the damage to Rs.130,000.

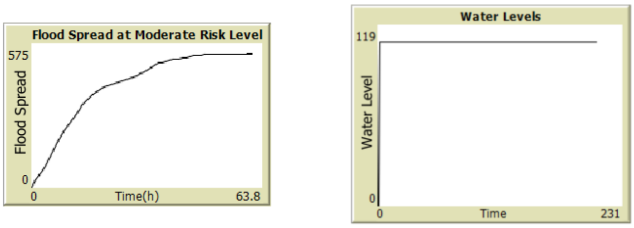


Figure 13. Flood spread and water level at moderate risk level over time(hours)

But as the river height, lake height, and rainfall level increase, the water level reaches a maximum of (200-231) cm in (1-2) hours, with estimated damage over Rs.150,000.

The moderate risk scenario highlights the importance of evacuation time, and the challenges that emerge due to the increase of the population densities. The longer evacuation times due to increase of population suggest that more organized and controlled evacuation strategies might be needed to prevent bottlenecks and ensure the safety of all individuals. Furthermore, the higher water level of the flood suggests that opening or building draining system might be necessary to reduce the damage. Furthermore, having sea in the region indicates the importance of the present of the sea since it reduces the water level.

These results highlight the need for effective evacuation plans that take population size and distribution into consideration. The findings also indicate that even moderate floods can lead to significant property damage, indicating the importance of early warnings system, prevention actions and building flood control systems to minimize losses.

3. **High Flood Risk Level**
The high-risk scenario in the model was designed to simulate extreme flood conditions. The focus was on how extensive the flood spread is, how the population responds, and the level of property damage caused.

The results for the high-risk level show that the flood is widespread and quite severe. The flood covers (80-90) % of the ground within (20-25) hours, with water levels reaching up to 125 cm within 2-5 hours(Figure 10). The damage is high, with estimated losses exceeding Rs.200,000 by damaging nearly 80% of the properties. The human response in this scenario is more serious, with evacuations taking much longer due to the severity of the flood. This takes nearly 119 hours including boat evacuations (72 hours) when the population is around 320. As the population increases, evacuation times exceed 130 hours, resulting in the loss of at least 1 to 5 people and indicating the extreme demand evacuation processes in high-density areas. Furthermore, the present of the sea, reduced the damage lower than to Rs.200,000.

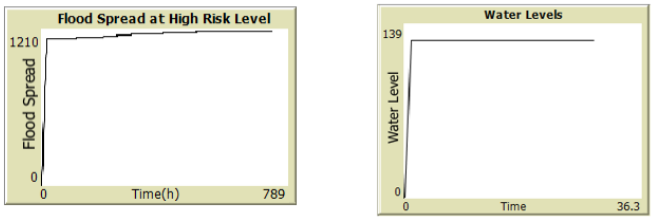


Figure 14. Flood spread and water level at high risk level over time(hours)

The high-risk scenario exposes the critical challenges faced during severe floods. The extensive flood coverage, rapid water level rise and high property damage show how quickly this situation can become serious. The extended time it takes to evacuate people, especially with regards to a large population and the loss of lives indicates the necessity of having a well-planned evacuation program that involves more than one way of transportation.

These findings emphasize the necessity for advanced planning and resource allocation to manage high-risk flood scenarios effectively. The result suggests that in high-risk areas, well planned evacuation strategies, including the use of more boats and other emergency transportation, are essential. Furthermore, significant property damage indicates that having better flood defenses, risk mitigation strategies and early warning systems are essential to reduce floods.

The following sections will discuss the some results that emerged from the model.

- **Flood Risk Levels Comparison**
A direct comparison of the results across the three risk levels highlights how flood severity, property damage, and evacuation time increase with the risk level. The low-risk scenario shows minimal impact, while the moderate and high-risk scenarios show significantly higher levels of destruction. Moreover, the loss of lives increases as the flood risk level rises.

This comparison emphasizes the importance of understanding the progression from low to high risk. It highlights the need for well-planned strategies at each risk level, with low-risk areas requiring more monitoring and high-risk areas requiring

Table 1. Table that covers the average result of the model.

Risk Level	Affected Area	Water Level	Flood Spread Time	Evacuation Time	Damage
Low	7%	90cm	(2-3)h	-	Rs.12,500
Moderate	35%	107cm	(2-3)h	35h	Rs.150,000
High	85%	125cm	(2-5)h	119h	Rs.200,000

Note: Obtained from Result & Discussion Section

immediate and comprehensive response plans.

- **Environmental Impact**
  This model also considers the environmental impact on flooding. The model's sensitivity to key parameters, such as rainfall intensity, river height, lake height and population density, and presence of sea is crucial for understanding its influence of the flood. Small changes in these inputs can significantly affect all outcomes that are mentioned above, especially rainfall intensity, river height, and lake height have a huge impact on water level rising. Specially presence of the beach leads to a small reduction of the total damage compared to when sea is not presented.

  These environmental impacts in the analysis provide a more border view of the flood's consequences. It supports making informed decisions and creates sustainable flood management practices that protect both people and the environment.

This section shows that as flood risk increases, the impact on human life and property worsens significantly. Population density, environmental conditions, and flood parameters are key factors in determining damage and evacuation efficiency. This highlights the need for well-planned flood management strategies that address both human and environmental concerns. And this section provides a clear understanding of the model response to different flood risk levels and supports the development of effective flood management strategies by considering human behavior and environmental impacts.

4. Conclusion

In summary, the Agent-Based Model (ABM) helps us understand and manage different levels of flood risk. It shows that low risk areas have minimal impact, but need continuous monitoring. Moderate risk areas suffer significant damage, especially with higher populations, while environmental features can help reduce this. High risk areas experience extensive damage and complex evacuations, so effective plans and flood defenses are crucial. Overall, the model emphasizes the need for tailored management and well-planned evacuations to reduce flood damage.

5. Code Files

This is show our flood risk management agent base modeling analysis using odd protocol and simulated by use AnyLogic, NetLogo softwares. And this repository is add those code files in gitHub.

Flood Risk Management GitHub Repository

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